Arctic Observing Summit (April 30 – May 2, 2013, Vancouver, Canada) white paper

"Status of the Beaufort Gyre Observing System (BGOS, 2003-2013): goals, objectives, capabilities, challenges and sustainability"

A. Proshutinsky, R. Krishfield, J. Toole (Woods Hole Oceanographic Institution, USA)
M.-L. Timmermans (Yale University, USA)
W. Williams, E. Carmack, F. McLaughlin (Institute of Ocean Sciences, Canada)
K. Shimada (Tokyo University of Marine Science and Technology, Japan)

Summary

By 2013, a full decade of observations, supported by NSF, Woods Hole Oceanographic Institution and the Department of Fisheries and Oceans, Canada, will have been obtained in the Beaufort Gyre (BG) region. To date, over 100 peer-reviewed publications by authors from different countries and institutions have utilized BG Observing System (BGOS) data. Some of the results suggest that the BG freshwater (FW) reservoir may be entering a period of freshwater release which would be expected from previous climatological behavior, however, it is unclear whether the Arctic climate has transitioned to a new regime where the freshwater will continue to accumulate and exceed anything observed in the past. *To improve our understanding of climatically important FW accumulation and release processes, and to reduce uncertainties in climate predictions, it is essential that the BG freshwater reservoir continue to be measured in the future in the same uninterrupted manner and at the same sustained locations to investigate the fate of the BG FW anomaly under rapidly changing climate conditions.* In October 2012 we requested renewed support from NSF to continue observing the BG freshwater reservoir by extending the BGOS observational program until 2018 at the same locations occupied since 2003, including the reinstatement of one mooring previously removed. This AON project aligns well with the main priorities outlined in the SEARCH Implementation Plan and compliments at least 10 other AON projects. We anticipate that the knowledge gained will continue to be vital to a wide variety of Arctic process and climate studies, to operational forecasting and other Arctic research programs, and will spur further valuable investigations of the Arctic Ocean.

The Arctic Ocean's Beaufort Gyre

The BG is a unique circulation component within the Arctic Ocean physical environmental system reflecting a set of specific atmospheric, sea-ice, and oceanic conditions that have significant interrelationships with the Arctic-wide as well as global climate systems (e.g. Proshutinsky *et al.*, 2002, 2009a,b, 2012b). One of the most striking observations in recent years has been a reduction in both sea-ice extent and thickness, with the most pronounced losses in the Canada Basin. The significant negative trends in observed sea-ice extent and thickness have prompted numerous ongoing debates about the root causes and resulting consequences of the rapid Arctic climate change; at present there are insufficient definitive observations or substantiated theories to reach a consensus among the different opinions.

Ocean changes in the BG Region (BGR, Fig. 1 left) have been as prominent as the disappearing sea-ice cover; in the period 2003-2012 the BGR accumulated more than 5000 km^3 of liquid FW, an increase of approximately 25% (update to Proshutinsky *et al.*, 2009b) relative to the climatology of the 1970s (Fig. 2). A FW release of this magnitude from the Arctic would be enough to cause a salinity anomaly in the North Atlantic (NA) with magnitude comparable to the Great Salinity Anomaly (GSA) of the 1970s, and possibly greatly influencing global climate by reduction of the ocean meridional overturning circulation (Vellinga *et al.*, 2008).

Changes in the FW balance influence the extent of the sea-ice cover, the surface albedo, the energy balance, the temperature (T) and salinity (S) structure of the water masses, and biological processes in the Arctic Ocean and its marginal seas. In the Arctic Ocean, the FW at the surface maintains a strong stratification that prevents release of significant deep-ocean heat to the sea ice and atmosphere (Aagaard and Carmack, 1989; Toole *et al.*, 2010). Loss of this FW cap could have grave consequences for the climate resulting in massive sea-ice melt. Re-establishment of the FW cap and strong stratification could then result in climate cooling as new sea-ice formation ensues.

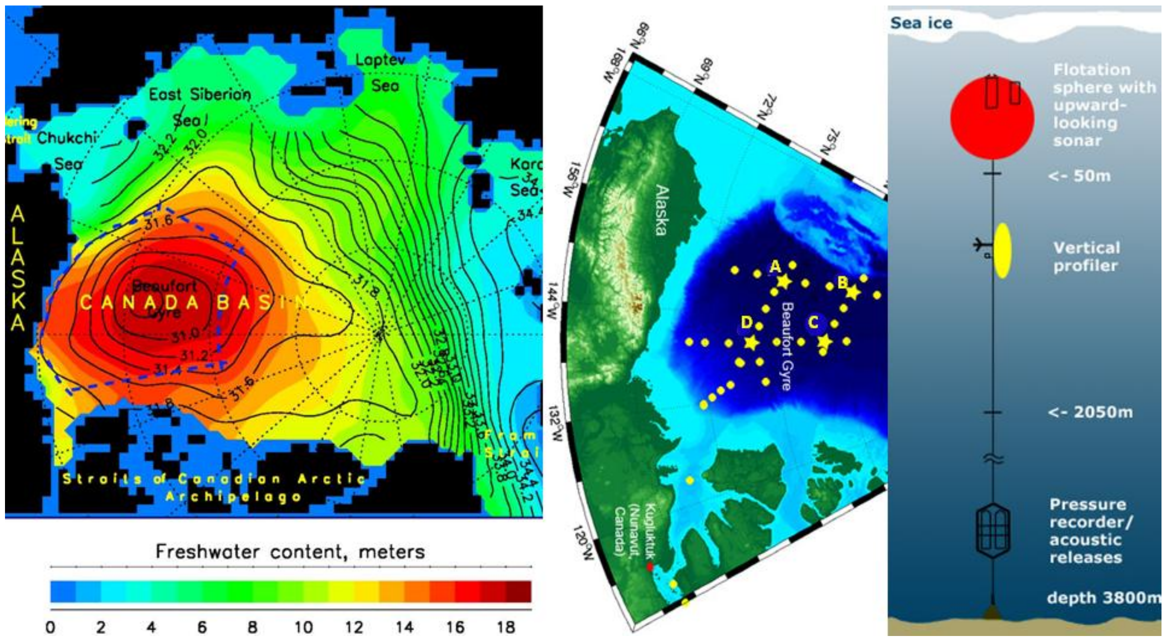

Figure 1 ***Left:*** *Climatology of Arctic FW content (FWC, m, colors). Solid lines depict summer 1950–1980 mean salinity at 50 m. FWC is calculated relative to a salinity of 34.8. The BGR is bounded by thick dashed blue lines;* ***Middle****: BGOS field program with locations of A,B,C, and D moorings (stars) and sites of CTD casts (circles);* ***Right:*** *BGOS mooring diagram with: (a) flotation-mounted Upward Looking Sonar (ULS), and ADCP; (b) McLane Moored Profiler (MMP) measuring T, S and currents between 50 and 2050m, (d) anchor, (e) acoustic releases and (f) anchor-mounted Bottom Pressure Recorder (BPR).*

The total liquid FW content (FWC) of the Arctic Ocean is around 80,000 km^3 (Serreze *et al.*, 2006; Aagaard and Carmack, 1989), which is typically calculated relative to a salinity of 34.8. The solid FW stored in sea ice was estimated to be about 17,000 km^3 (Aagaard and Carmack, 1989) but only 10,000 km^3 by Serreze *et al.* (2006) 16 years later. It is climatically important that FW stored in both the ocean and sea ice is unevenly distributed over the surface of the Arctic Ocean (Fig. 1) and that the distributions change significantly over seasonal to decadal time scales due to the influence of varying sources and sinks, thermodynamic and wind forced (Proshutinsky *et al.*, 2009a,b). Greater than half of the Arctic Ocean's liquid FW is concentrated in the Canada Basin, centered in the BGR (Fig. 1, left), while more than half of the solid FW is stored against the Canadian Arctic Archipelago (CAA) and Greenland in a solid FW reservoir of multiyear ice.

The BGR in the southern portion of the Canada Basin with its unique FW reservoir (Fig. 1, left) contains more than 20,000 km^3 of liquid FW (Aagaard and Carmack, 1989; Carmack *et al.*, 2008; Proshutinsky *et al.*, 2009a,b). This volume is at least 5 times larger than the total annual river runoff to the Arctic Ocean and approximately two times larger than the amount of FW stored in sea ice in the entire Arctic Ocean.

Proshutinsky *et al.* (2002, hereafter *P2*) hypothesized that since the 1950s, the Arctic Ocean has released significant volumes of liquid FW to the NA at least 4 times, with approximately decadal periodicity (Fig. 3, updated from *P2*). *P2* and Dukhovskoy *et al.* (2004, 2006a, b; hereafter *Dab*) hypothesized that these periodic FW releases were associated with natural climate oscillations in the Arctic/NA system, where fluxes of FW and heat between the Arctic and NA regulate these oscillations between different atmosphere/ice/ocean circulation regimes. In this system, anticyclonic winds during anticyclonic circulation regimes (ACCRs) accumulate FW in the BGR due to Ekman transport convergence, while cyclonic winds during cyclonic circulation regimes (CCRs) release FW from the BGR and transport these waters to the NA via Fram Strait and the straits of the CAA (Fig. 3). It has also been suggested that in addition to liquid FW, sea ice could be released from the CAA reservoir (Fig. 2) during CCRs (Proshutinsky and Johnson, 1997; Kwok, 2008) increasing total FW release during CCRs.

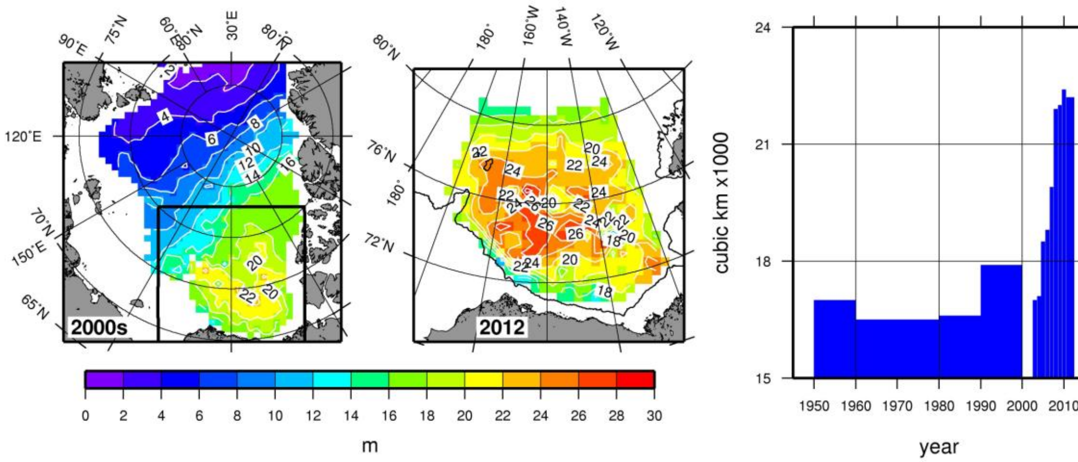

Figure 2 ***Left****: Mean summer FWC (m) in the 2000s. The BGR is depicted by the box.* ***Middle****: 2012 summer FWC (m) from BGOS data.* ***Right****: Decadal summer FWC (thousands of km^3) in the BGR before 2000 and annual after2000. The unprecedented increase of FWC in the BGR in 2003-2012 relative to previous decades manifests dramatic changes in the Arctic climate and warns that release of this freshwater may have significant consequences to Arctic and global climate.*

Considering the two circulation regimes, the release of FW from the Arctic would have been likely during CCRs of 1953-1957, 1963-1971, 1980-1985, and 1989-1996 (Fig. 3). Increased export of FW from the Arctic Ocean can be inferred from information about NA GSAs: FW export in 1963-1971 preceded (with a time lag of 2-3 years) the GSA of the 1970s (described by Dickson *et al.*, 1988), and similarly the GSAs of the 1980s, and 1990s (described by Belkin *et al.*, 1998) were observed during cyclonic regimes of 1980-1985 and 1989-1996, respectively. This indirect information can be taken as observational evidence supporting the hypotheses of *P2* and *Dab*. It is of note, however, that there was, to our knowledge, no documented NA freshening in the 1950s. Past evidence for changing Arctic Ocean FW may be inferred from the decadal-mean gridded fields of ocean T and S for the 1950s, 1960s, 1970s, and 1980s in the Environmental Working Group Atlas of the Arctic Ocean (EWG, 1997, 1998). However, these data cannot be used to quantitatively compare FW content (FWC) in the Arctic Ocean and the BGR between ACCRs and CCRs because the timing of regime changes does not coincide with calendar decades. On the other hand, EWG data can be used to conclude that the BGR FW reservoir is a permanent feature of the Arctic Ocean and can be considered as a flywheel of Arctic Ocean circulation (*P2*, Proshutinsky *et al*., 2009b; 2013).

The Beaufort Gyre Observing System (BGOS)

FWC: In 2003, a pilot expedition was made to the BG to measure seasonal changes in T and S fields, ocean currents, sea level, sea-ice conditions and geochemical parameters to better understand how the system works. For these preliminary observations, moorings and hydrographic site locations were planned to provide the best possible coverage of the BG FW reservoir assuming that this reservoir location coincided with its climatologic position of the 1970s – 1990s (Fig. 1). Three moorings were deployed (moorings A, B and C, Fig. 4, left), with mooring B in the center of the BG climatologic FWC maximum. We hypothesized that the observed transformations of FW at these mooring sites would reflect changes in the entire BGR.

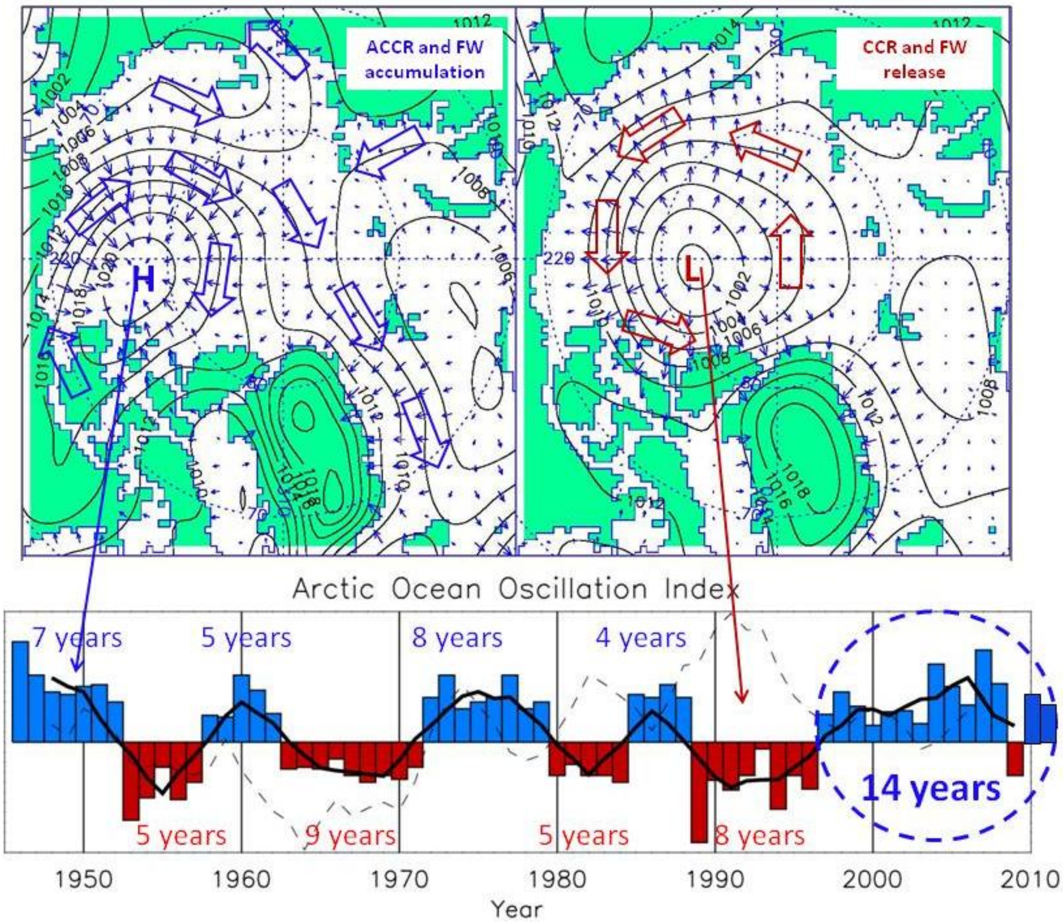

Figure 3 ***Top panels*** *show SLP (black lines, hPa) wind directions (large arrows) and Ekman transport (blue small arrows) typical for ACCRs (**left**) with Ekman transport converging; and CCRs (**right**) with Ekman transport diverging.* ***Bottom panel*** *shows that circulation regimes and Ekman transports alternate between ACCRs (blue bars) and CCRs, (red bars) with a period of 10-14 years while during the last 14 years a strong ACCR has dominated resulting in an unprecedented FW accumulation in the BGR. Dashed black line shows Arctic Oscillation index (Thompson and Wallace, 1998).*

2003 data clearly demonstrated that new BG conditions differed significantly from the FWC climatology (in Fig. 4 left compare colors and solid lines depicting FWC in 2003 and climatology, respectively). The center of the FWC maximum shifted to the southeast and appeared to contract in area relative to climatology, while lateral gradients of surface dynamic height (and baroclinic flow) increased. In 2004, BGOS was continued (Fig. 4 middle), with the addition of a 4th mooring (D) deployed in the new center of the FWC maximum. In 2009 (Fig. 4 right), we ended observations at mooring C because of budget constraints, while all other observational sites remained unchanged. Observations between 2009 and 2012 indicated that the center of the FWC maximum shifted slightly toward mooring A (Fig. 4, right). Note that in 2012, two Japanese moorings (black stars, J1 and J2, Fig. 4, right) were added to complement BGOS. These moorings will effectively monitor FW, heat fluxes, and changes in sea ice drafts at the BG western boundary, which would likely to be in the path of some of the liquid and solid FW that could be released from the gyre.

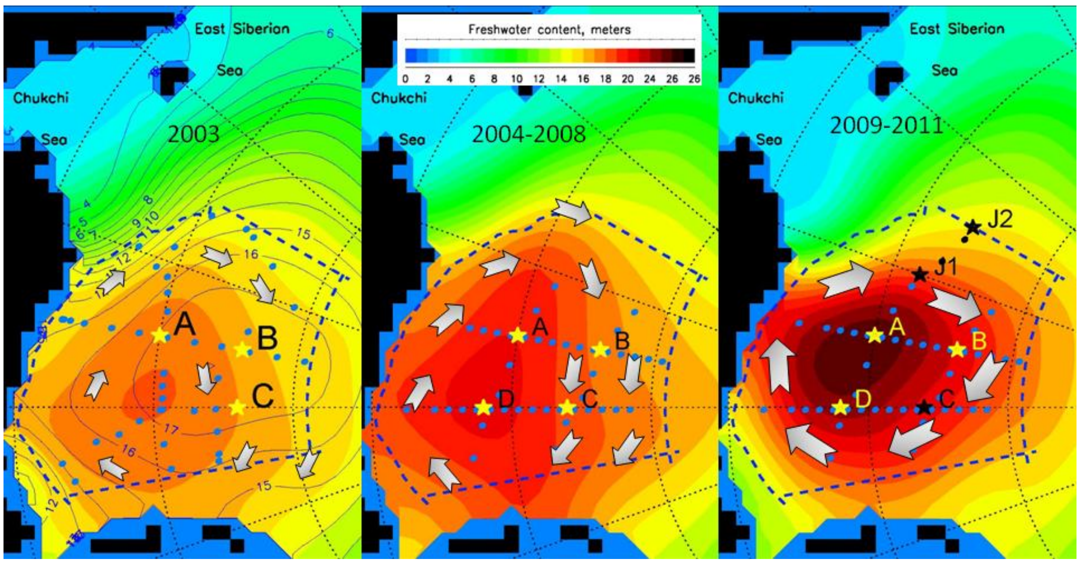

Figure 4 ***Left:*** *2003 FWC (m, colors) from 2003 BGOS observed hydrography. Thin solid lines show FWC (m) from EWG climatology.* ***Middle:*** *2004-2008 FWC with 4 moorings. Mooring D was deployed in the center of the FWC maximum.* ***Right:*** *2009-2011 FWC and mooring locations. Note that mooring C was not in place in 2009-2011. In 2012 two Japanese moorings (black stars, J1 and J2) were added to BGOS. For the 2014-2018 program, we have proposed to add mooring C (black star) to return the observational system to the configuration of the 2004-2008 period. Blue dots show CTD station locations (in left panel – actual; in middle and right panels – standard sites only). Arrows depict approximate direction and intensity of the BG geostrophic circulation in 2003, 2004-2008 and 2009-2011 for left to right panels, respectively*

Sea-ice: Sea ice thickness (SIT) measurements are made under BGOS and combined with ice concentration data for the estimation of sea-ice volume and seasonal changes of the BG FW balance. SIT data from BGOS moorings has been extensively used for validation of satellite products (e.g. Kwok, 2011; Laxon *et al.*, 2013), and for validation and recalibration of Arctic Ocean Model Intercomparison (AOMIP) models (e.g. Johnson *et al.*, 2012; Schweiger *et al.*, 2011). The BGOS data are also included in R. Lindsay's "SIT data archive" supported by the NOAA Climate Program Office (http://psc.apl.washington.edu/sea_ice_cdr/).

To assess the suitability of BGOS mooring locations for the 2004-2008 observational program, AOMIP PIs [S. Häkkinen (GSFC), F. Kauker (AWI, Germany), and G. Holloway (IOS, Canada)] calculated correlation coefficients between time series of SIT and sea-ice volume over the entire Arctic Ocean using their respective regional coupled ice-ocean model results for the period 1950-2005. Interestingly, while the location of the correlation maximum differed slightly between models (not shown), there was a consistently high probability of occurrence of this maximum correlation in the BGR. This suggests that measurements obtained in the BG are representative of the entire Arctic, i.e., SIT and concentration reduction at BGOS moorings mirror sea-ice volume loss over the entire Arctic. In fact, the fraction of open water observed at all mooring sites (not shown) correlates well with total ice extent in the Arctic Ocean and sea-ice extent minima in 2007-2010. In general, we observe a marked trend from thicker to thinner (or ice free) categories, consistent with melt. These results evince the effectiveness of the BGOS moored array design not only for resolving the important solid FWC fraction, but for understanding sea-ice change in the BGR and Arctic wide

Hydrography and ocean dynamics: Annual hydrographic surveys (Fig. 4) are made in conjunction with BGOS to obtain long-term water property observations at standard locations to document interannual changes in FWC, heat content, and geochemistry. In addition to changing sea-ice and FWC, significant variations have been observed in ocean heat content (e.g. Jackson *et al.*, 2010, 2011; McLaughlin *et al.*, 2011) and geostrophic currents (e.g. McPhee *et al.*, 2009; Fig. 4). Based on Ice Mass Balance Buoy data deployed during a BGOS expedition, Perovich et al. (2008) showed that an increase in the open water fraction resulted in a 500% positive anomaly in solar heat input to the upper ocean, triggering an ice–albedo feedback and contributing to the accelerating ice retreat. Numerous hypotheses have been put forward to explain the causes of sea-ice reduction in the BGR, among them hypotheses stating that the major cause is heat release from deeper layers. In general, this contradicts our physical understanding of mixing processes and mechanisms of heat release under the dominating influence of the strong Arctic halocline (Toole *et al.*, 2011). That said, under certain conditions such as extreme storm events (Yang, 2004, 2009; Pickart et al, 2012; Schulze *et al.*, 2012, Zhang et al., 2013), release of deep ocean heat may be possible, particularly in the boundary regions of the Canada Basin. On the other hand, our analysis of measurements through the double-diffusive staircase forming the upper boundary of the Atlantic Water layer indicates that vertical transport of heat from the Atlantic Water in the central BGR does not contribute significantly to the surface heat budget (Timmermans *et al.*, 2008a). This work highlights the importance of quantifying and monitoring energetic processes, such as winds and tides which can mix deep-ocean heat to the surface, as the BG ice pack evolves seasonally and interannually.

Ocean currents are directly measured at BGOS mooring sites by McLane Moored Profilers (MMPs) and upward-looking Acoustic Doppler Current Profilers to document changes in BG kinetic energy and to characterize changes in the flow field that occur in conjunction with sea-ice and atmospheric circulation changes. The first interesting and important results were obtained by analyzing tidal currents. It was found that the magnitudes of tidal constituents for both sea level and currents increase with a reduction of sea-ice. Similar results were obtained by Pnyushkov and Polyakov *et al.* (2012) in the Laptev Sea. In addition, BGOS measurements frequently reveal energetic mesoscale eddies at all depths in the water column. Eddy water mass properties allow us to infer eddy origins, pathways and formation mechanisms in the BGR (see Timmermans *et al.*, 2008). We are still working with other moored ocean current data including those from the upward-looking ADCPs.

Bottom pressure/sea level*:* Bottom pressure recorders (BPR) have been included on all BGOS moorings to investigate ocean dynamics. One major finding shows that the seasonal cycle in the BG averaged for 2003-2006 and the seasonal cycle from a BPR at the North Pole Environmental Observatory (NPEO) in 2004-2005, resemble the mean 2003-2006 sea level seasonal cycle at 9 coastal stations along the Siberian coast (Fig. 7 right, Proshutinsky *et al*, 2007). This implies that the Arctic Ocean experiences practically-synchronic changes of its volume throughout its domain. *What forcing is responsible for the observed seasonal variability of bottom pressure in the Arctic Ocean? Why do the entire BGR and North Pole bottom pressure data exhibit synchronic changes and why do these data correlate so well with the coastal sea level data?* One explanation may be associated with changing Arctic Ocean volume due to water fluxes via its connecting straits and passages to lower latitudes (Peralta-Ferriz *et al.*, 2011). BGOS BPR data have been essential to this and other recent studies (e.g. Peralta-Ferriz and Morison, 2010; Morison *et al.*, 2007, 2012) to understand large-scale Arctic Ocean dynamics and change. We have collaborated with S. Laxon (UK) to validate remote sensing technology to infer Arctic Ocean SSH. Giles *et al.* (2012) built on our BG studies and observations (Proshutinsky *et al.*, 2002, 2009b) in an analysis of satellite observations (validated based on BGOS BPRs and used together with BGOS hydrography) to infer BG FW dynamics.

Geochemistry: The major results of the BGOS geochemistry program are central to our understanding of the Arctic climate system and continuation of these observations will be of utmost importance for:

FW composition: Yamamoto-Kawai et al. (2009a) described the composition, structure and residence time of sea-ice melt, brine rejection, Pacific water and meteoric water in the BG for 2003-2004. Guay et al. (2009) further considered meteoric water sources, finding little North American runoff but up to 15.5% Eurasian runoff. During the rapid increase in BG FW over 2005-2007, Yamamoto-Kawai et al. (2009a) found that sea-ice meltwater increased by 2.7m in the central BGR and low-salinity water from the Mackenzie River was advected to the southern BGR. This knowledge of FW origins is key to understanding changes to large-scale ocean dynamics, water pathways, and the hydrological cycle.

Ocean acidification: Yamamoto-Kawai et al. (2009b, 2011) found that surface waters of the BG became undersaturated with respect to aragonite in 2008 - the first sign of acidification in the global deep ocean. Three factors contributed: reduced sea-ice extent (~30%), increased sea-ice melt (~30%), and anthropogenic CO2 (~40%). The deeper Pacific Winter Water is also undersaturated, due to anthropogenic CO2, with negative implications for shelled benthic organisms during upwelling to shelf ecosystems (Mathis et al., 2011). BGOS measurements are a critical element to understanding the impact of anthropogenic CO2 in the Arctic.

Organic carbon cycle: Hwang et al. (2008) analyzed sediment traps at BGOS mooring A, finding that, unlike other ocean basins, the bulk of particulate organic carbon entering the deep BGR is supplied by horizontal advection from the surrounding margins and that both the organic and inorganic carbon cycle in the Arctic is inherently linked to ocean dynamics.

Ecosystem Effects: McLaughlin and Carmack (2010) noted that FW changes from 2007 to 2009 in the BG depressed the top of the halocline and increased the stratification there by 25%, thus deepening the upper nutricline and associated summertime subsurface chlorophyll maximum and making nutrients less available. These harsher conditions coincided with a shift in near-surface ecosystem structure towards the smallest plankton (Li et al., 2009).

BGOS connections with other observing systems/programs

BGOS has had strong ties through logistics and data sharing to at least ten other AON projects, with looser associations with many others. Closely linked programs include: the Ice-Tethered Profiler (ITP) contribution to the Arctic Observing Network (J. Toole), Autonomous Ice Mass Balance Buoys (IMB) for an Arctic Observing Network (J. Richter-Menge), Ocean-Ice Interaction Measurements Using Autonomous Ocean Flux Buoys (AOFBs) in the Arctic Observing System (T. Stanton), The Collaborative O-Buoy Project: Deployment of a Network of Arctic Ocean Chemical Sensors for the IPY and beyond (P. Matrai), UpTempO: Measuring the Upper Layer Temperature of the Arctic Ocean (M. Steele), and additional buoys deployed during BGOS cruises that comprise the International Arctic Buoy Programme (IABP) (I. Rigor). Ice-based buoys that make up these programs have been deployed in the BGR during

BGOS cruises since the inception of the BGOS program and provide complimentary information on atmospheric, snow, sea-ice and upper-ocean conditions to the data from BGOS moorings.

Other vital physical connections between BGOS and elements of AON include Bering Strait measurements under “The Pacific Gateway to the Arctic - Quantifying and Understanding Bering Strait Oceanic Fluxes” (R. Woodgate) and “An interdisciplinary monitoring mooring in the western Arctic boundary current: Climatic forcing and ecosystem response” (R. Pickart). These moorings are natural extensions of the BGOS moorings and enable further constraints on water mass pathways and dynamics in the region. As shown in Figure 2 of the SEARCH Implementation Plan, the combined mooring set covers the priority areas in the envisioned Distributed Marine Observatory. Further, the BG sea-ice and surface waters are coupled to the sea-ice and water characteristics at the North Pole (“Aerial Hydrographic Surveys for IPY and Beyond: Tracking Change and Understanding Seasonal Variability”, J. Morison) and in the Switchyard region (“A Modular Approach to Building an Arctic Observing System for the IPY and Beyond in the Switchyard Region of the Arctic Ocean”, P. Schlosser) via the northern extension of the BG and the Transpolar Drift. These water-mass pathways ultimately bring Arctic waters to Fram Strait (where a mooring array is supported by the Alfred Wegener (Germany) and Polar Research (Norway) Institutes.

Why do we need a long-term Beaufort Gyre Observing System?

It is critical that the present BGOS configuration (mooring locations and hydrographic sites), be maintained with the same basic structure as during the 2003-2013 observational period. The multi-decadal history of circulation regime changes suggests that the current ACCR may shift to a CCR in the very near future. Continuing BGOS observations are likely to detect and quantify FW release from the BGR, which has never been documented before. In fact, the magnitudes of FWC in 2011 and 2012 were modestly less than in 2010 (Proshutinsky *et al.*, 2011, 2012, 2013; Fig. 3) and atmospheric conditions over the Arctic in January-September of 2012 (not shown) were favorable for FW release. The change may have already begun.

On the other hand, some speculate that the Arctic has, or may, reach a climatic "tipping point", where the rules that governed the natural decadal variability of the Arctic system in the past have changed (Lindsey *et al.*, 2005). In that case, the current ACCR could conceivably persist over the next 5 years, in which case it would again be imperative to continue observations in the BGR to measure and understand the extraordinary changes in all environmental parameters that would result from an unprecedented domination of the ACCR over the region.

The central scientific challenges and fundamental rationale to continue the long-term BG Observing System project are dictated by the questions of whether significant changes in the mechanics of the BG flywheel can be expected in the future, if, when and how will FW be released from the BGR, and how will changing FW distributions impact environmental conditions in the Arctic and NA.

Scientific questions: The following subset of scientific questions outlines the essential motivation for the BG observing system: *(1) What is the origin of the salinity minimum in the BGR? (2) How does this salinity or freshwater content change in time? (3) What are the driving forces of the BG circulation and how stable is the BG system? (4) What is the current state of the BG system? (5) How does the BG system change from season to season and from year to year during different climate states and what is the range of its interannual and decadal variability? (6) What is the role of the BG system in Arctic climate change?*

We have resolved some of these important questions through detailed analysis of BGOS measurements since 2003, but only for the ACCR conditions that have prevailed these past 14 years. In particular, we found that:

- seasonal change in BG total FWC ranges from 5% to 10% of the total FWC depending on the intensity and sense of the atmospheric circulation;
- interannual changes can reach as much as 1500 km^3;
- decadal changes were approximately 1000 km^3 per decade prior to 2000; an accelerated rate of change of about 5,000 km^3 per decade characterizes the period since 2003;
- during the present ACCR the BG geostrophic circulation has intensified (McPhee *et al.*, 2009) and the baroclinic component of the Transpolar Drift current intensified and shifted toward Canada, accelerating sea-ice drift and redistributing sea ice in this region;
- there are three major causes of the FWC changes observed in the BG at different timescales, namely: (i) wind-generated Ekman Pumping (EP) which represents the mechanical part of the ocean FW redistribution, (ii) ocean mixing and changes to stratification, and (iii) sea-ice transformations accompanied by the release of either FW or salt.

Observed changes in the BGR (circulation, freshwater and heat content) have been annually summarized and published in BAMS (Richter-Menge et al., 2006, 2007; Proshutinsky *et al.*, 2009, 2010, 2011,2012), posted on the BG project web site and in the NOAA Arctic Report Card: http://www.arctic.noaa.gov/reportcard/.

While much progress has been made, there are still significant gaps in our understanding of this important component of the climate system. It is important to test hypotheses and investigate interrelations among different processes and mechanisms under the CCR climate state, or to measure the system (during a transformation from the accepted natural decadal variability) under conditions of a long-term ACCR. Given the latter, continued measurements will allow us to answer several questions of consequence to Arctic and global climate: *(1) How will the hydrographic structure of the Arctic Ocean change under long-term ACCR forcing? (2) Is there a saturation level for freshwater accumulation in the BGR? (3) How will long-term ACCR forcing influence sea-ice conditions and the accumulation and release of heat from the upper ocean?*

Recommendations for a sustained BGOS

The results and ongoing studies supported by the BGOS program have already proven to be invaluable to the Arctic research community on many levels. It is crucial for the scientific goals and objectives of the Arctic studies formulated above to continue BGOS measurements of T, S, currents, geochemical tracers, sea-ice draft, and sea level. Moorings should continue to measure the variations of ocean temperature, salinity and currents, bottom pressures, biogeochemistry via sediment traps, ice draft and surface wave parameters at the same locations instrumented since 2003. Hydrographic sections should be maintained to measure the variation of the BGR water-column, with a full suite of geochemical properties, in addition to T and S measured at each hydrographic station.

Given the relatively minor interannual changes in the location of the FWC center during last 10 years, mooring and hydrographic station locations should be maintained without change for the next observational cycle of 2014-2018, judging that these locations are ideal for observing FWC variability in the region and also to maintain observational continuity. We also recommend re-instating mooring C (black star, Fig. 4, right) to return the observational system to the configuration of the 2004-2008 period. Observations at site C are needed to constrain freshwater and heat content and fluxes at the periphery of the BG. Absence of these observations after 2009 resulted in some uncertainties in our analyses of the BG behavior during the last 5 years, particularly given that site C is likely in one of the pathways of potential FW release.

We further recommend that: BGOS continue to be coordinated with national and international partners including other AON elements; BGOS logistics continue to be made available to the Arctic community; collected data continue to be open, free, and fully available via the project web site (immediately after completion of data processing and data quality control) and at the Advanced Cooperative Arctic Data and Information Service (ACADIS, http://www.aoncadis.org).

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